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Modified Smoldering Test of Urethane Foams Used in Anechoic Chambers

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A program is under way at the Naval Research Laboratory to develop small-scale laboratory fire tests that will predict more accurately the behavior of Class A materials in fires. After development of five small-scale performance specifications for assessing the hazard of carbon-impregnated polyurethane foam, samples of the materials were installed in a large-scale fire test facility to determine the scaling parameters applicable to the foam. The knowledge gained from the large-scale tests under different experimental conditions and with several polyether and polyester foams has been used to scale down to a laboratory test that dynamically measures the expected behavior of the foam in a scaled situation.

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MODIFIED SMOLDERING TEST OF URETHANE FOAMS USED IN ANECHOIC CHAMBERS

INTRODUCTION

Since the 1973 fire in a Naval Research Laboratory anechoic chamber [1], several other fires involving carbon-impregnated polyurethane foam have occurred at various facilities [2,3]. The hazard of these chambers has been highlighted, and the public finally recognizes this long-existing problem.

The absorber material in these chambers presents several unique problems. First, the least expensive available material with the desired qualities, including required electrical characteristics, is polyurethane foam. The dangers of this base material are its self-smoldering properties and its toxic gas emission under thermal and fire stress [4]. Second, the types of fire retardants that can be used are limited because of restrictions placed on the end product. The end product is heavily loaded with carbon for specific electrical characteristics, and fire retardants used must not interfere with this function.

The Chemistry Division at NRL has been actively involved since 1973 in a research program to improve the fire behavior of the absorber materials on the market, and five fire performance tests have been conceived and developed [4,5]. These have been adopted as performance specifications in procurement contracts for chamber materials used by various governmental, institutional, and commercial agencies. Since the development of the small-scale fire performance tests, a large-scale testing program has been developed to determine scaling parameters applicable to the small-scale test results, for more accurate prediction of real-life performance.

One of the small-scale tests described in Ref. 4 evaluated the smoldering tendency of foams after ignition by a hot surface heater. This was the most severe test conceived, but it did not take into account the effects of heat transfer (heat feedback), fuel load, sample geometry, or other, more subtle scaling parameters encountered in full-scale fires involving this material. The large-scale testing program was to simulate a full-scale chamber so that these factors could be reevaluated. This program produced knowledge that has been used to reassess the small-scale smoldering test procedure and to evolve a redesign that better indicates the material's behavior under fire conditions in actual anechoic chambers.

EXPERIMENTAL SETUP AND PROCEDURE

The seven materials used in the first large-scale testing program were submitted by several of the companies that supplied foams for the program from which the test specifications were developed. The samples will be referred to by the letters A through G.

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Each manufacturer has been deeply involved in improving its product since the performance specifications were developed. Although there may be several foams from the same company, each represents the state-of-the-art material for its company at the time of receipt.

Large-scale tests were carried out in the 1.8 m × 1.8 m × 2.4 m (6 ft × 6 ft × 8 ft) facility shown in Fig. 1. The walls, floor, and ceiling of this chamber were covered with absorber material in the configuration used in actual chambers. Although the entire interior of the chamber was covered with foam, the absorber under test at any time covered only a 0.6 m × 0.6 m (2 ft × 2 ft) area surrounding the location of the ignition source. The ignition source used was an 80-W hot-surface cartridge heater 1.27 cm (0.5 in.) in diameter and 16.5 cm (6 in.) long, as used in Test 3, Ref. 4. In the small-scale tests [4] we had found that the cartridge heater is a more severe form of ignition than the 1900°C methane-air flame required by Test 2 (Table 1). When a flame is played on a sample of the foam, the area in contact with the flame is burned away, creating a cavity, so that the only significant forms of heat transfer are radiative and convective. With the cartridge heater, heat is more efficiently transferred through conduction because of the constant contact between the heater and the foam. Conductive heat transfer is more effective in allowing heat to build up in the foam to the point at which combustion can sustain itself; heat buildup then depends on the ability of the foam to dissipate the energy rapidly.

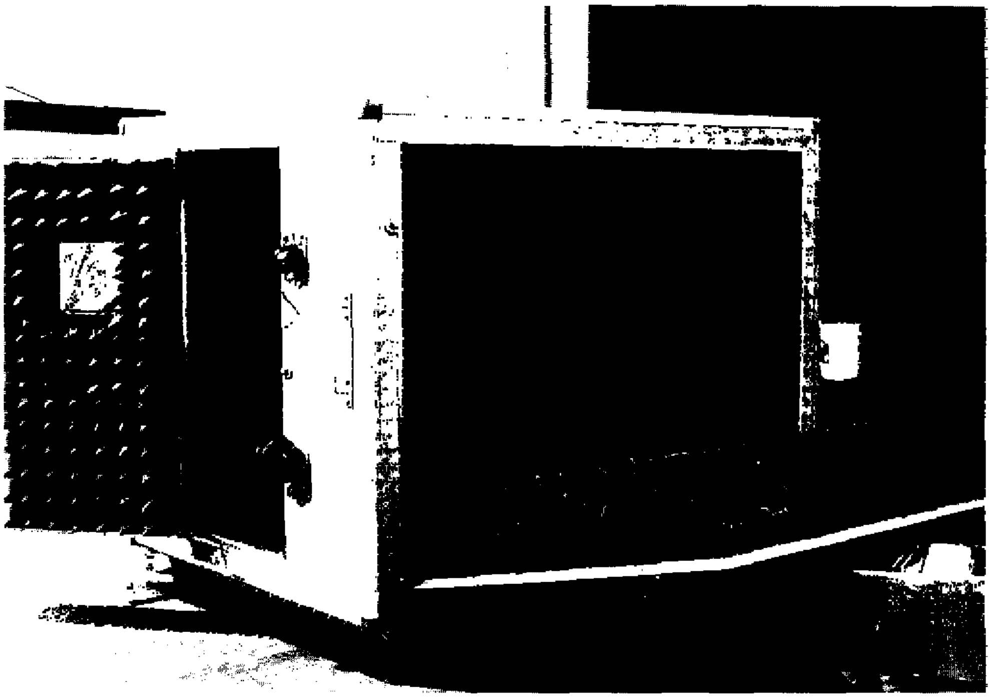

Fig. 1 — Interior view of model anechoic chamber used to conduct large-scale absorber fire tests

Table 1 — Summary of Performance Specification Tests

Test	Equipment for Test	Property Tested	Experimental Conditions	Requirements Under Test Conditions
1. Resistance to electrical stress	Power supply (capable of 240 V ac, 8 A) Test leads located 2.5 cm apart	Ability to withstand electrical overload or short	Exposure to 240 V ac for 60 s	Self-extinguish within 60 s after removal of ignition source. Specimen damage <90%
2. Ease of ignition and flame Propagation	Bunsen burner Support for specimen Timing device	Ignitability and ability to self-extinquish flame (flaming ignition source)	Exposure to flame for 60 s	Self-extinguish within 60 s after removal of ignition source
3. Smoldering	Radiative cartridge heater (capable of 600°C)	Ability to self-extinguish smoldering (flameless ignition source)	Exposure to 600°C radiative heat source for 5 min	Specimen damage <90%
4. Toxic gas emission in a fire environment	Combustion boat H_2/air flame Closed chamber	Toxic gas production Under continuous exposure to flaming ignition source (T = 2400°C)	Exposure to flame for 15 min	HCN conc. <0.3 mg/g HC1 conc. <0.4 mg/g CO conc. <20 mg/g
5. Toxic gas emission due to a hot surface	Combustion boat Radiative cartridge heater Closed chamber	Toxic gas production under continuous exposure to flameless ignition source (T = 350°C)	Exposure to radiative heat source for 15 min	HCN conc. <0.6 mg/g HC1 conc. <0.9 mg/g CO conc. <5 mg/g

The fire spread within the absorber is monitored by a thermocouple array that covers one side of the chamber and extends to cover half of the back (Fig. 2). The thermocouples are spaced on a square grid 30.5 cm (12 in.) apart and extend 7.6 cm (3 in.) into the absorber attached to the wall. Two additional thermocouples are used, one attached to the cartridge heater and the other inserted 2.54 cm (1 in.) away from the cartridge heater. The thermocouples were inserted in the back of the foam through holes drilled through the chamber wall and the foam. The thermocouples were protected during insertion by 0.6 cm X 10.2 cm (0.25 in. X 4 in.) stainless steel tubing. This was removed after the thermocouple was in place, and the hole was repaired with General Electric RTV-112 potting compound.

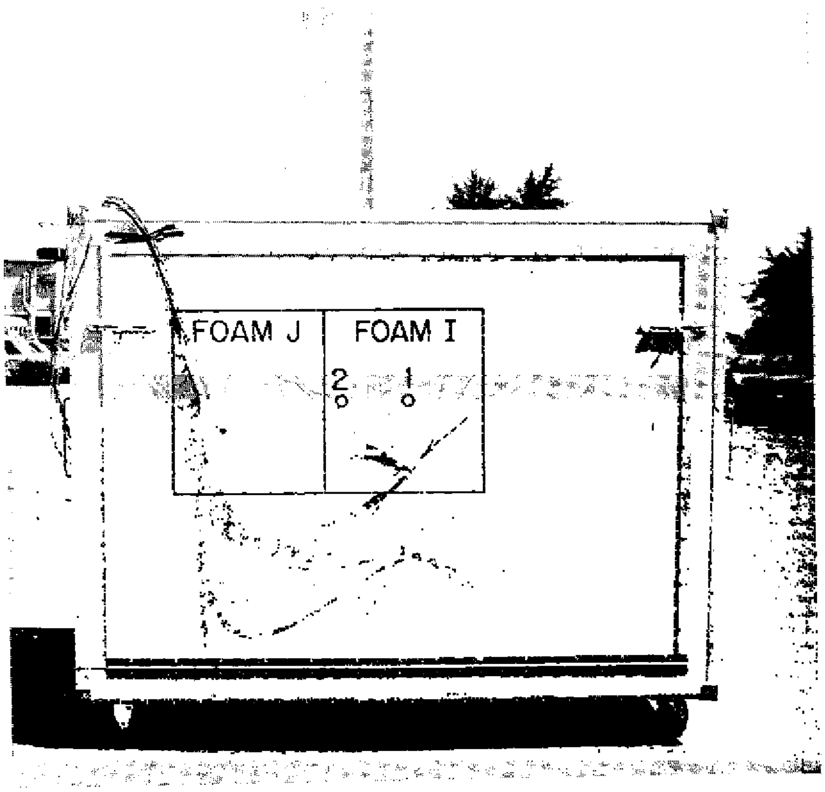

Fig. 2 — Side view of model chamber, showing thermocouple array

A stack located on top of the chamber houses the fire detectors (one photoelectric detector, two ionization detectors, and one toxic product monitor) used for sensing a fire (Fig. 2) and the gas sampling lines through which are continuously monitored, in some tests, oxygen (Beckman Instruments, Model 715) and carbon monoxide and dioxide on two analyzers (Beckman Instruments, Model 315A). Temperatures within the foam are recorded during fire tests by a Hewlett Packard Model 3480 Scanning Digital Voltmeter and output on paper tape at a rate of approximately one reading every 2 s. Subsequent computer plots of the data permit correlation of temperature profiles with the progress of the fire in the chamber.

The cartridge heater was imbedded in the base of the foam that was attached to the wall of the chamber. The heater temperature was then raised to the desired value, either stepwise in 100°C intervals or directly to maximum temperature, and then removed after all fire detectors were in the alarm mode. Monitoring of the temperatures was continued after removal of the ignition source to determine the extent of fire spread and time of extinguishment.

RESULTS AND DISCUSSION

The data from the large-scale fire tests are tabulated in Table 2. A typical computer plot generated during one of these fire tests is shown in Fig. 3. In the upper left-hand corner of the figure is the thermocouple (TC) configuration of the entire side wall on which the fire was initiated. In this particular test, the damper on the stack was 30% open but the blower to circulate air in the chamber was not activated. Thermocouple 39 monitors the temperature of the heater. From this figure we can follow the fire spread, which was negligible as indicated by the minimal responses of thermocouples 12, 13, 17, and 18 in the immediate vicinity of the fire.

Table 2 — Summary of Large-Scale Chamber Fire Tests

Sample	Maximum Temperature of Heater (°C)	Method of Reaching Temp.	Maximum Temperature of TC 2.5 cm Away (°C)	Max. Energy Input (kW)	Fire Test	Outcome
F	600	Stepped	—*	186	23	Smoldered
D	600	Stepped	460	176	11	Smoldered
E	600	Stepped	500	258	21	Smoldered
D	600	Stepped	410	172	16	Self-exting.
G	600	Stepped	550	160	22	Smoldered
C	600	Stepped	260	186	19	Self-exting.
C	600	Stepped	270	204	20	Self-exting.
B	600	Stepped	375	147	9	Self-exting.
D	560	Direct	460	157	13	Self-exting.
D	520	Direct	450	60	12	Self-exting.
C	600	Direct	400	—	18	Self-exting.
B	600	Direct	290	—	10	Self-exting.
B	600	Direct	220	—	14	Self-exting.
B	310	Direct	110	—	8	Self-exting.
A	300	Direct	—	—	3	Self-exting.
A	425	Direct	>550	—	4	Smoldered
A	440	Direct	—	—	1	Smoldered
A&D	600	Direct	630	47	17	Smoldered
A&B	600	Direct	520	—	15	Smoldered

* — Indicates data not available.

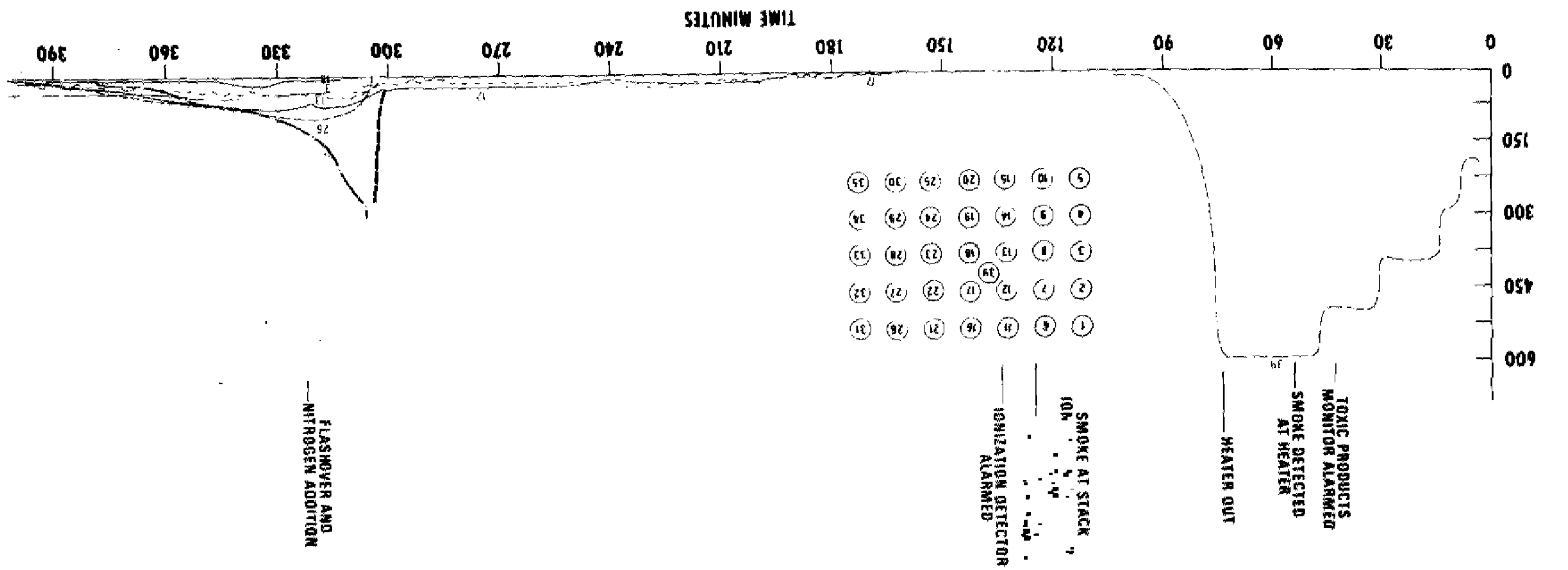

Fig. 3 — Fire scenario depicting the temperatures of several thermocouples during initiation and propagation of a fire that resulted in flashover in the large-scale facility

Under these minimal ventilation conditions, the fire was monitored for an additional 4 h after the heater was removed. At this time the combustible gases from the smoldering foam ignited, and rapid combustion spread throughout the chamber foam. This phenomenon is one form of "flashover" and is evident in the figure at 305 min into the test. This necessitated termination of the test, accomplished by flooding the chamber with nitrogen to suppress the fire. Following flashover, the fire was fought with nitrogen for approximately 1 h before being extinguished. More than 50% of the absorber material lining the chamber walls was destroyed during the later phase of the fire, post flashover (Fig. 4).

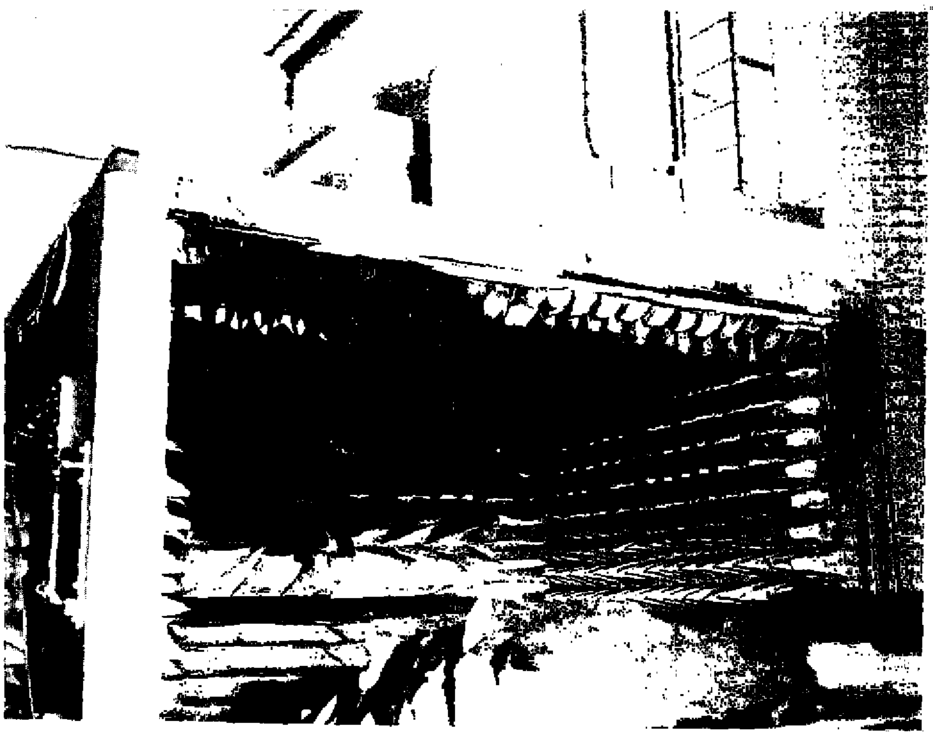

Fig. 4 — Appearance of large-scale facility after flashover fire

The fire was not halted before the 350 min point because the thermocouples indicated that the material was sustaining, rather than suppressing, smoldering. The fundamental characteristic being evaluated in the large-scale tests is the ability of the carbon-impregnated polyurethane foams to suppress smoldering when the heat source is removed. Correlations were attempted between smoldering and several other factors, such as the amount of heat or energy input (maximum temperature), time to reach maximum temperature (heating rate), and method of heat input (stepped or direct).

Attempts to predict the self-extinguishing ability of these foams based on maximum temperature reached or time and method of reaching maximum temperature individually were unsuccessful. The one factor common to each large-scale fire test was the maximum temperature reached by the thermocouple 2.54 cm (1 in.) away from the heat source. In these tests, if this thermocouple failed to exceed the temperature range of 450° ± 10°C, the material could self-extinguish once the heat source was removed. This ability is related to the insulating quality of the char produced by the decomposing foam. Since it is neither very realistic nor practical to run large-scale tests on all materials to determine their smoldering capability, this knowledge can be used in redesigning the small-scale smoldering test to give more reliable results. The essential ingredients of this modified test would be

1. Increased sample size, so that the fuel load represented will minimize heat loss to the exterior. The close packing arrangement of anechoic chambers minimizes heat dissipation in case of ignition.

2. Monitoring of the conductive heat transfer at some distance from the heat source to determine the heat being propagated through the char to the virgin foam. A critical temperature (450°C-460°C at a thermocouple 2.54 cm away) must not be exceeded if the char formed is to protect the remaining foam from being consumed.

This type of information will give specific information on the insulating qualities of the char and its effectiveness in controlling conductive energy transfer. These ideas have been incorporated in the modified Smoldering Test Procedure that appears in Appendix A.

Correlations of Modified Small-Scale and Large-Scale Test Results

Two additional urethane foams (I and J) were subjected to the modified small-scale test. This test uses 20.5 cm × 20.5 cm × 20.5 cm (8 in. × 8 in. × 8 in.) samples and monitors the temperature 2.54 cm (1 in.) from the hot-surface ignition source. The test procedure outlined in Ref. 4 (Test 3) was followed, and the ignition source was removed 5 min after reaching 600°C.

The results with these two samples are shown in Fig. 5. The thermocouple 2.54 cm (1 in.) from the cartridge heater did not exceed 280°C during the test on product I, and smoldering was suppressed within 10 min after the heater was removed. On the other hand, the thermocouple 2.54 cm (1 in.) from the heater exceeded 600°C during the test of foam J. This foam was reduced completely to char before smoldering was suppressed.

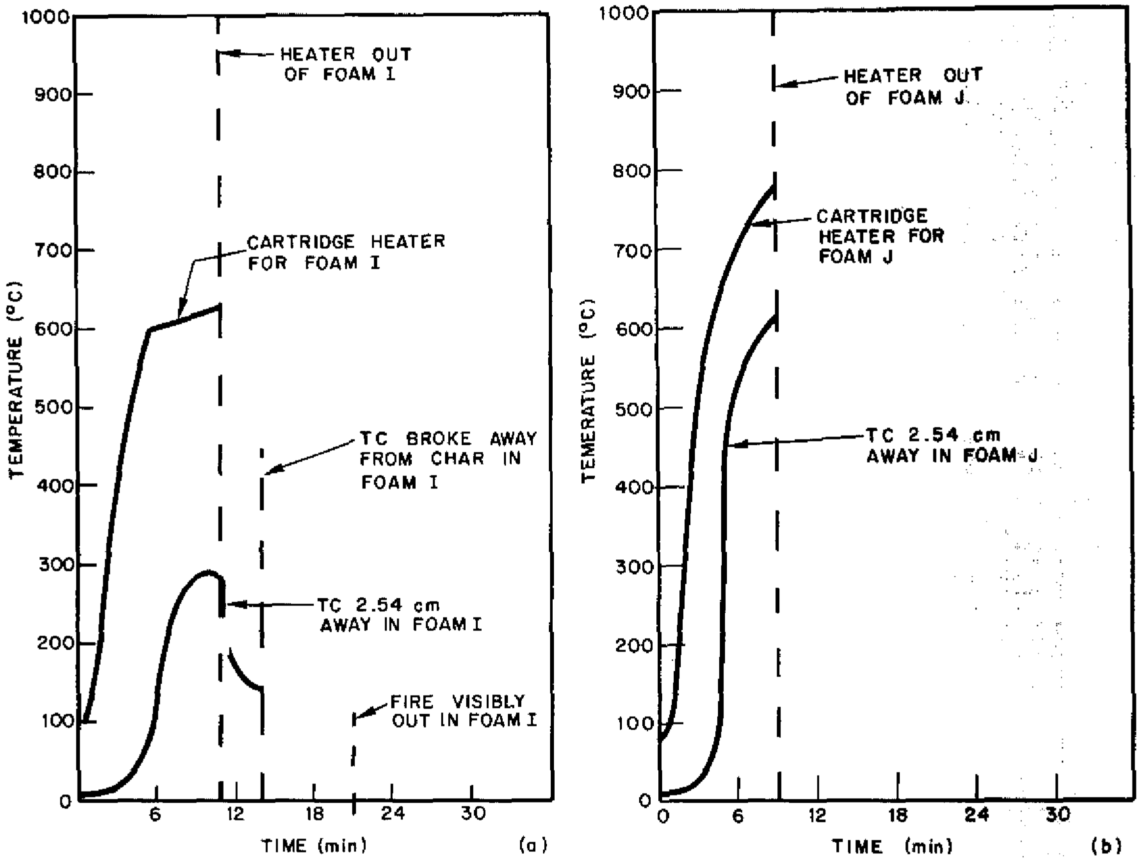

Fig. 5 — Thermocouple responses of Samples I and J during modified small-scale smoldering tests

Based on these measurements, foam I would not be expected to create the smoldering hazard that foam J would. To test this prediction, the same two foams were installed in the large-scale facility, as shown in Fig. 2, and examined under two modified large-scale test procedures. In the first test the hot-surface ignition source was inserted in foam I in position 1 (Fig. 2), and the temperature was increased to 900°C over a 20-min. span. The temperature of the thermocouple 2.54 cm (1 in.) away never exceeded 450°C during the test period, which spanned 25 min. The performance of this foam was satisfactory in that it self-extinguished the smoldering initiated by the heater and prevented additional material from being consumed after the heater was removed.

The hot-surface ignition source was again inserted in foam I in position 2 (Fig.2), which is bordered by foam J. The temperature of the ignition source was raised to 600°C over 15 min. The ignition source temperature was not increased further, but as the combustion spread into foam J, the temperature of the thermocouple 2.54 cm (1 in.) away began to rise and peaked at 800°C as the fire intensified. Foam J was incapable of suppressing the fire, and special additional measures had to be taken to extinguish the fire.

It is evident from these results that the modified small-scale test provides a qualitative basis for correlation to large-scale tests. It thus provides a simple, inexpensive way of predicting fire performance without engaging in an involved testing program. Many samples tested under both large- and small-scale test procedures have confirmed the usefulness of this modified test.

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Appendix A

PERFORMANCE SPECIFICATIONS FOR ANECHOIC-CHAMBER MATERIALS

TEST 1 — RESISTANCE TO ELECTRICAL STRESS

Specimens: — Three 5.2 cm × 15.1 cm × 15.1 cm (2-in. × 6-in. × 6-in.) samples. The surface area of the specimen in which the test leads are inserted shall not be covered with a surface fire retardant.

Equipment: — A 240-V a.c. power supply capable of 8-A output; test leads of AWG copper wire with 90° bends 1.9 cm (0.75 in.) from the ends.

Procedure: — The insulation is removed from the test leads to expose 1.3 cm (0.5 in.) of bare wire. The leads are inserted to a depth of 1.3 cm (0.5 in.) in the foam, 2.54 cm (1 in.) apart. They are horizontally supported so that they do not rest on the specimen. Power shall be applied to the specimen for 60 s. The specimen fails the test if it does not self-extinguish (no visible flame, smoke, or smoldering) within 60 s after the power has been turned off. If it does self-extinguish, the specimen is left undisturbed for 30 min and then reinspected; any specimen that is more than 90% (by weight) destroyed has failed the test. The specimen is then opened to expose its interior and is inspected for any evidence of remaining combustion (hot embers, smoke, or flame); any visible combustion rates the material as unsatisfactory.

TEST 2 — EASE OF IGNITION AND FLAME PROPAGATION

Specimens: — Five cubes, 5.2 cm (2 in.) or larger on each side. The bottom of each specimen shall not be covered with surface fire-retardant paint.

Equipment: — A laboratory ringstand with necessary clamps, suitable for supporting and positioning the specimen; a laboratory Bunsen burner adjusted to a height of 7.6 cm (3 in.) and producing a flame temperature of 1900°C; a time device permitting measurements of intervals of 1 s or less.

Procedure: — The test is conducted in a location free of drafts. The specimen is exposed so that the flame is directed at the bottom center of each specimen for 30 s. If the burning part of the specimen melts or shrinks away from the flame, the burner is moved to keep the specimen continuously in the flame. If the specimen self-extinguishes (no visible flame, smoke, or smoldering) within 60 s after the flame is withdrawn, it has passed the ignition test. For a material to be classified as self-extinguishing by this test, every specimen must self-extinguish within 60 s after flame withdrawal.

TEST 3 — MODIFIED SMOLDERING TEST (REVISED 1976)

Specimens: — Three cubes, 20.1 cm (8 in.) on each side.

Equipment: — A high-density electric cartridge heater 1.3 cm (0.5 in.) in diameter and 15.1 cm (6 in.) long, capable of being inserted snugly into a 7.6-cm (3 in.) deep hole in the specimen and of reaching a maximum temperature of 600°C; two thermocouples, capable of measuring temperatures to 1000°C.

Procedure: — The tests are conducted in a laboratory hood. One thermocouple is physically attached by temperature-resistant tape to the cartridge heater and inserted vertically into a hole in the specimen 7.6-cm (3 in.) deep. The second thermocouple is inserted into the specimen top 2.54 cm (1 in.) from the cartridge heater. Both the thermocouple and cartridge heater/thermocouple pair are supported so that they remain upright and imbedded in the specimen throughout the test. The heater is inserted in the specimen and the temperature is raised to 600°C. The heater is left in the specimen at 600°C for 5 min before being removed. The temperature of the thermocouple 2.54 cm (1 in.) from the heater is monitored throughout the test period. The test is considered over only when all visible smoldering has ceased (no smoke, flame, or hot embers). The specimen has failed if at any time during the test period the temperature of the thermocouple 2.54 cm (1 in.) from the heater exceeds 450°C ± 10°.

TEST 4 — TOXIC GAS EMISSION IN A FIRE ENVIRONMENT

Specimens: — Three 1-g quantities of 0.63-cm (0.25 in.) cubes.

Equipment: — A combustion boat capable of containing 1 g of the specimen; a 2400°C hydrogen-air torch adjusted to a height of 1.3-2.54 cm (0.5-1 in.) (Either the boat or the flame must be movable to allow exposure of the entire sample to the flame during the test — total involvement of the sample is required); a closed chamber capable of containing the boat with the specimen and the torch, equipped to ignite the torch remotely and sample the concentrations of CO, HC1, HCN, and O_2 and large enough that the O_2 concentration does not fall below 20% during the test; detector tubes or other instrumentation for measuring the concentrations of CO, HCN, and HC1 gases at the end of the test.

Procedure: — The combustion boat containing the specimen is placed in the closed system. The torch is remotely ignited and directed at an angle, from above the specimen for 15 min at a distance no greater than 0.63 cm (0.25 in.) from the specimen. During this time, the entire specimen must be exposed to the torch. At the end of the 15-min exposure, the concentrations of HCN, HC1, and CO are measured. Their productions are reported in terms of milligrams of combustion product per gram of specimen. If toxic gas production exceeds the following limits, the specimen has failed the test.

Combustion Product	Milligrams of Product per gram of Specimen
HCN	0.3
HC1	0.4
CO	20.0

Failure of any of the specimens rates the material as unsatisfactory.

TEST 5 — TOXIC GAS EMISSION DUE TO A HOT SURFACE

Specimens: — Three 1-g quantities of 0.63-cm (0.25-in.) cubes.

Equipment: — The combustion boat, closed chamber, and sampling devices used in Test 4; a radiative cartridge heater capable of generating a temperature up to 350°C.

Procedure: — The combustion boat containing the cubes is placed in the closed system with the heater lying on top of the cubes so that it heats all of the sample during the test. The heater is then remotely activated and allowed to heat to 350°C. The specimen is heated at this temperature for 15 min. During this time, the sample must be totally involved. At the end of the 15-min exposure, the concentration of CO, HCN, and HC1 gases are measured and reported in terms of milligrams of combustion product per gram of specimen. If toxic gas production exceeds the following limits, the specimen has failed the test.

Combustion Product	Milligrams of Product per gram of Specimen
HCN	0.6
HC1	0.9
CO	5.0

Failure of any specimen rates the material as unsatisfactory.